

## On the Stability of Particles in Extrasolar Planetary Systems

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**Abstract.** In this paper, we present preliminary results on the stability of massless particles in two- and three-planet systems. The results of our study may be used to address questions concerning the stability of terrestrial planets in these systems and also the trapping of particles in resonances with the planets. The possibility of the existence of islands of stability and/or instability at different regions in multi-body systems and their probable correspondence to certain resonances are also discussed.

### 1. Introduction

The discovery of multi-body extrasolar planetary systems during the past few years has once again confronted astrodynamacists with the old question of the stability of such systems. The discovery of GJ 876 where two planets are locked in a 2:1 mean-motion resonance (Marcy et al. 2001), the confirmation of three planets in orbit about Upsilon Andromedae (Butler et al. 1999), and the discovery of planetary systems around 47 Uma and 55 Cancri with planets in orbits more closely resembling those in the solar system (Fischer et al. 2002; Marcy et al. 2002) have set the grounds for a deeper look at the problem of the stability of multi-body systems. Here we present a preliminary investigation of the dynamical stability of the 47 Uma and 55 Cancri systems. A more detailed analysis, including similar work on GJ 876 and  $\nu$  And, will be addressed in future work.

### 2. Methodology

We performed dynamical fits to the radial velocity data for the stars 47 Uma and 55 Cancri using a Levenberg-Marquardt minimization algorithm (Press et al. 1992) as in Laughlin & Chambers (2001) and Rivera & Lissauer (2001). We assumed that the planets in each system were coplanar and that the plane of the planets contained the line of sight. We then used the resulting fitted parameters as initial conditions for N-body simulations. In order to give the resulting systems the ability to explore extra degrees of freedom, we artificially added a mutual inclination of one degree. We also performed simulations of each system in which hundreds of (massless) test particles were added. All test particles were started on circular orbits with respect to the central star. No test particles were placed in regions such that a test particle would initially cross the

orbit of a planet. The results may be used as an indication of the presence and locations of potential terrestrial planets in these systems.

The simulations were performed with the second-order mixed variable symplectic (MVS) integrator in the MERCURY integration package (Chambers 1999), which is based on the technique pioneered by Wisdom & Holman (1991). This code was modified to include the principal effects of general relativity, as in Lissauer & Rivera (2001).

### 3. 47 Uma

In agreement with Fischer et al. (2002), we find that in dynamical fits to the radial velocity data for 47 Uma, the value of  $\chi^2_\nu$  does not change significantly for a fit with the eccentricity of the outer companion in the range 0 to 0.2. When we fit for the eccentricity of the outer planet, the fitting routine converged on a value of 0.19. Note that this value is near the boundary of stability determined by Fischer et al. (2002). A long-term simulation of the system based on this fit is stable over billions of years. In this simulation, the two companions are in a 5:2 mean motion resonance. Also, throughout the simulation the orbits are nearly anti-aligned. Table 1 gives the parameters from the fit at epoch JD 2446959.737, and Figure 1a shows the nearest and farthest points in the companions' orbits vs. time for the first 1 Gyr of a long-term simulation based on the parameters given in Table 1. Figure 2 shows the eccentricities, inclinations, and the period ratio of the companions over short times.

Figure 1b shows the stability of test particles in a 10 Myr simulation of the same system. It shows the time that a test particle was lost vs. its initial semi-major axis. The dots and lines toward the bottom of the figure indicate the initial semi-major axes and radial excursions of the planets. Note that islands of instability occur at the locations of several mean motion resonances with the planets. Also, exterior to the outer companion, there are islands of stability between mean motion resonances. Since 47 Uma is similar to the sun, the region around 1 AU is of particular interest. Unfortunately, the 3:1 mean motion resonance with the inner companion lies in this region, and there are signs that the region may not be stable. Note that while only the one test particle at 1 AU was lost in less than 10 Myr, proximity to the 3:1 mean motion resonance could endanger the stability of other nearby orbits over longer timescales.

Table 1. Astrocentric orbital parameters for the 47 Uma and 55 Cancri systems.

Parameter	47 Uma		55 Cancri		
	inner	outer	inner	middle	outer
Period (days)	1082	2735	14.65	44.58	5582
$e$	0.034	0.190	0.021	0.169	0.141
$\omega$ (deg)	133	284	104	56	202
Mean Anomaly (deg)	351	329	340	345	189
$m_{\text{pl}}$ ( $M_{\text{Jup}}$ )	2.65	0.90	0.84	0.20	4.21

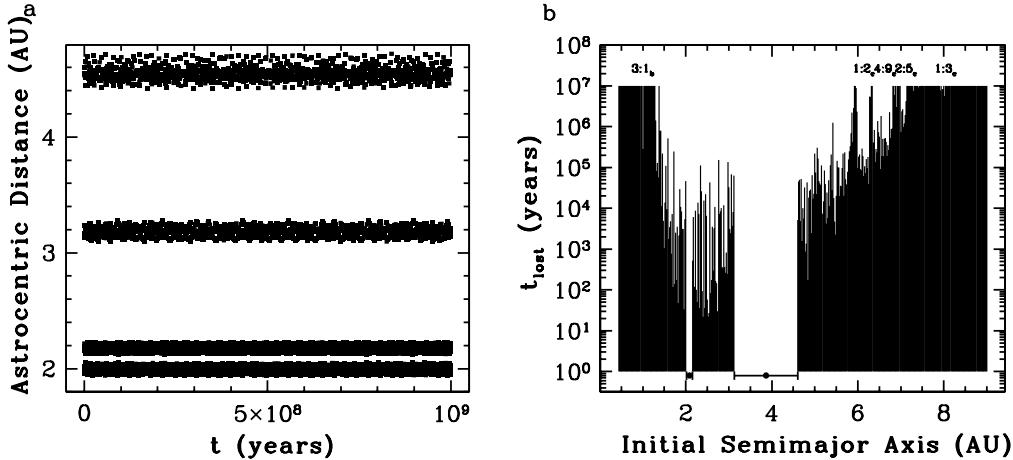


Figure 1. (a) Periastra and apastras of the companions of 47 Uma.  
(b) Stability times of test particles in the 47 Uma system.

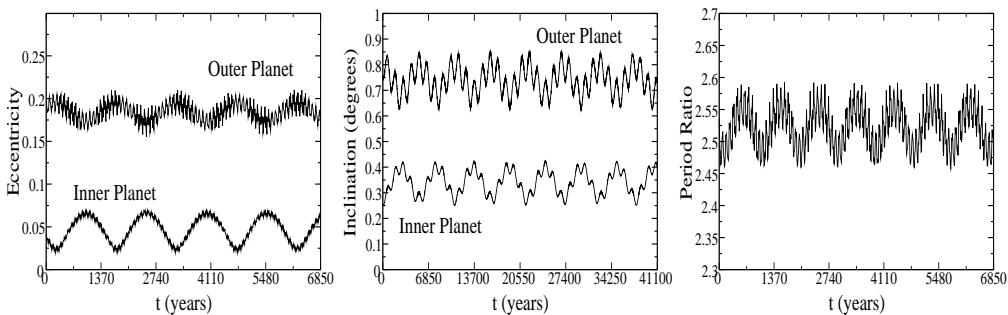


Figure 2. Eccentricities, inclinations, and period ratio of the companions of 47 Uma.

#### 4. 55 Cancri

This system proved to be difficult to fit with the Levenberg-Marquardt routine. We obtained two fits with almost the same  $\chi^2_\nu$  value with very different parameters for the outer planet. This is an indication of the large uncertainties in this planet's orbital parameters. Table 1 gives the parameters from one of our fits at epoch JD 2450250.0, and Figure 3a shows the periastron and apastron of each planet vs. time from a simulation based on this fit. The simulation shows that the inner and middle companions are near a 3:1 mean motion resonance. These results are in agreement with Marcy et al. (2002).

Figure 3b shows the stability of test particles in a 5 Myr simulation of the same system. It clearly shows a large stable region between the middle and outer companions. This is in rough agreement with Marcy et al. (2002), in which they showed that a terrestrial planet on a circular orbit at 1 AU would be stable.

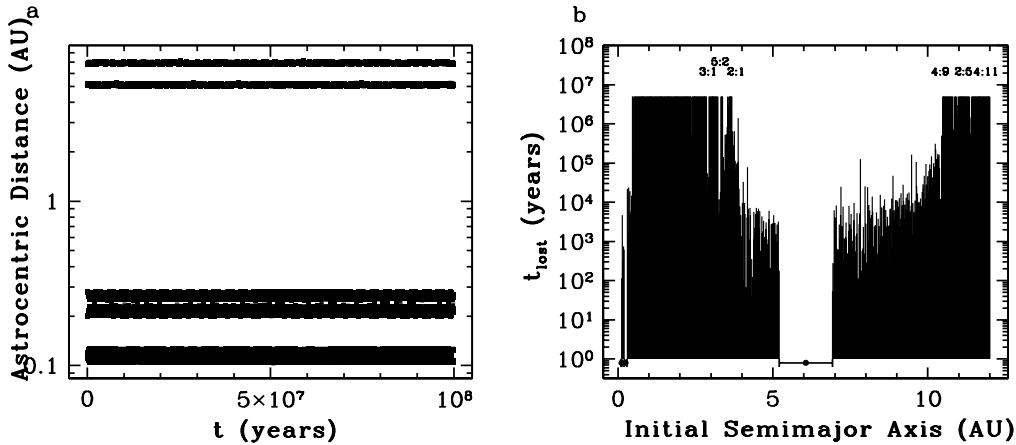


Figure 3. (a) Periastra and apastras of the companions of 55 Cancri.  
(b) Stability times of test particles in the 55 Cancri system.

## 5. Summary

We have presented results on the stability of the 47 Uma and 55 Cancri systems with and without massless particles. Dynamical fits were used to determine the initial conditions for the simulations. A large area of parameter space is consistent with the observations. The area around 1 AU in the 47 Uma system may not harbor a terrestrial planet, while the opposite is true in the 55 Cancri system. These results are in rough agreement with previous studies (Fischer et al. 2002; Marcy et al. 2002).

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